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PILOT RESPONSE TO A GROUND PROXIMITY WARNING SYSTEM IN HIGHLY M--ETC(U)
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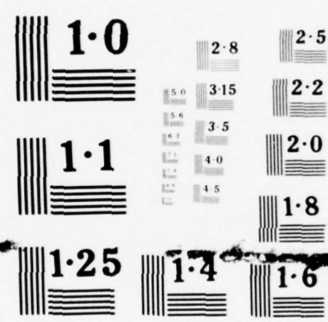

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PILOT RESPONSE TO A GROUND PROXIMITY WARNING SYSTEM IN HIGHLY MANEUVERABLE AIRCRAFT

CREW EQUIPMENT AND HUMAN FACTORS DIVISION
DIRECTORATE OF EQUIPMENT ENGINEERING
DEPUTY FOR ENGINEERING

JUNE 1976

TECHNICAL REPORT ASD-TR-76-5
FINAL REPORT FOR PERIOD MARCH 1974 to MAY 1975

Approved for public release; distribution unlimited

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

This technical report has been reviewed and is approved for publication.

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It is of interest to the USAF whether a Ground Proximity Warning System (GPWS) similar to the type currently in production for commercial airlines could be used in highly maneuverable aircraft such as fighters and trainers. A GPWS was installed in the Crew Station Design Facility (CSDF) FB-111 Simulator, and missions were flown over various types of terrain in both VFR and IFR conditions. Reaction data was recorded, and the subjects completed questionnaires. It was concluded that pilot acceptance was high and that a workable set of warning envelopes could probably be developed for highly maneuverable aircraft.

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FOREWORD

The work reported in this document was performed at the Crew Station Design Facility (CSDF), Crew Station, Escape, and Human Factors Branch (ASD/ENECC) of the Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, over the period March 1974 to May 1975, under Job Order Number ASDD-0008, on behalf of ASD Project 2713, Task 30 Ground Proximity Warning Study.

The report is a description of a study investigating the feasibility of using a Ground Proximity Warning System in high performance, highly maneuverable aircraft. The study was conducted for the Flight Instruments Branch, Deputy for Engineering, Wright-Patterson AFB, Ohio, who funded the necessary development work on the CSDF simulator and its operating costs during the study.

The principal investigators were Squadron Leader Christopher J. Hyatt, RAF, and Mrs Frances A. Kniess.

The ground proximity warning system simulator capability was developed by George Sayre and Mark Christensen of the Singer Company, Simulation Products Division, under contract F33-615-71-C-1921. This report was submitted by the authors March, 1976.

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SECTION I
INTRODUCTION

Much work has been done over the last four years to develop an inexpensive, compact, lightweight system which would provide adequate warning of an aircraft's inadvertent controlled flight into terrain. A workable system now exists and variants of it are being manufactured by different contractors. The system is being fitted to all commercial passenger carrying jet aircraft as a result of new Federal Aviation Administration (FAA) requirements. The USAF wishes to take advantage of any benefits the system can offer and installation in all USAF passenger carrying aircraft is being considered. The question has naturally arisen whether the system as designed, or with suitable modifications, could usefully be applied to other types of aircraft such as highly maneuverable combat aircraft. This study, intended to provide a first look at the problem, was to determine whether further investigation would be worthwhile.

The study was initiated as a result of discussions between the Flight Instruments Branch (ASD/ENFI) and the Human Factors Branch (ASD/ENCTH) over the period October 73 to February 74. It was conceived as a low cost study, with most of the expenditure directed to the creation of a Ground Proximity Warning System (GPWS) simulation capability. The study was carried out in two phases. The first consisted of flying a Visual Flight Rules (VFR) mission over a mountainous terrain model. Because visual cues tended to conflict with the warning system, a second phase was flown under Instrument Flight Rules (IFR) conditions, with terrain following radar cues available to the subject.

SECTION II
APPARATUS

The apparatus used for conducting this experiment was the Crew Station Design Facility's (CSDF) FB-111 simulator at Wright-Patterson Air Force Base. This simulator, driven by a CDC Sigma 5 computer, consists of modified FB-111 cockpit mounted on a 5 degree of freedom Singer motion base (vertical and lateral translation; pitch, roll, and yaw rotation).

The cockpit has a Wide Angle Commercial (WAC) window for its visual system, driven by a monochrome television probe operating on a SMK 23 terrain model. For the purpose of this experiment Singer Simulation Products Division developed a probe altitude sensor, operated by tracking an obliquely impinging laser beam. This generates real-time altitude-above-ground signals from the terrain model for the radar altimeter in the cockpit. This unique capability allows the whole terrain model to be used (rather than limited routes with ground heights stored in memory) and also permits changes to the terrain model without the need for any software change to the radar altitude system. The simulator also has an inertial navigation system and terrain following (TF) radar, both of which are coupled into the autopilot. Thus, fully automatic TF cross-country missions can be flown. Alternatively the autopilot can be uncoupled, and TF and navigation data given to the pilot by means of the Attitude Director Indicator (ADI). Altitude data for the TF system is obtained from radar landmass plates representing actual North American terrain. This is a standard system, but this was the first time it had been activated on the facility's simulator.

1. GROUND PROXIMITY WARNING SYSTEM (GPWS)

The simulated GPWS installation took data from the basic aero program of the simulator. Radar altitude data was taken from the probe altitude sensor for visual flight missions and from the TF system for instrument flight missions. The warning envelopes used are shown in Figures 1 and 2. It was not considered feasible to continually update these to current FAA configurations.

The GPWS is activated when the aircraft enters the appropriate warning envelope and continues to give warning until the aircraft leaves the envelope. The following forms of warning were provided:

a. A swept tone (Whoop-whoop!) fed to the simulator interphone system.

b. A voice saying "Pull Up!", fed to the simulator interphone system.

c. An illuminable warning panel bearing the legend PULL UP.

Switching facilities were available at the simulator console to select any or all of these warnings. If the voice and tone were selected together, they operated sequentially, tone followed by voice (Whoop-whoop! Pull Up! Whoop-whoop! Pull Up!).

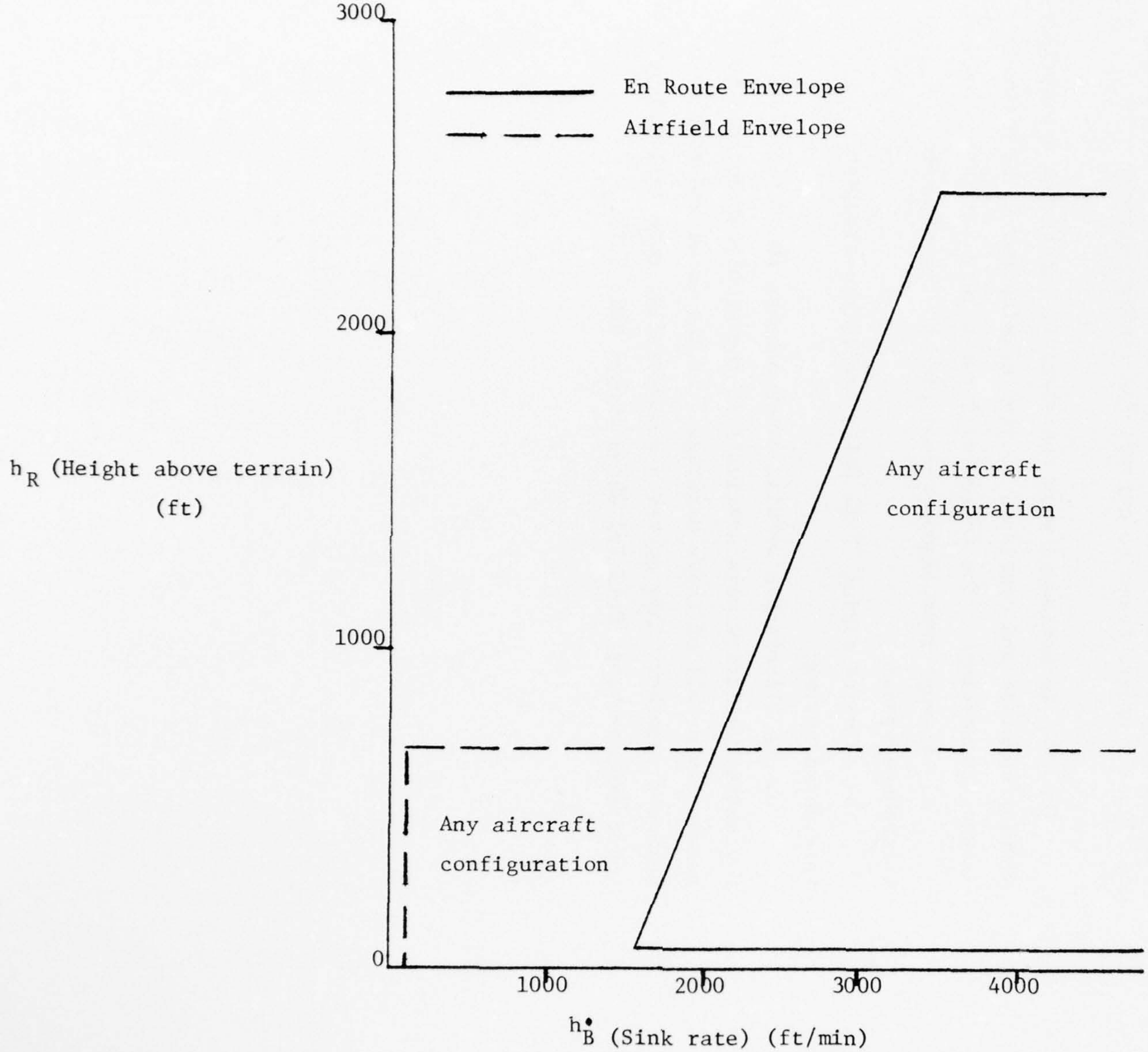


Figure 1 Proximity Warning Envelope (Sink Rate Modes 1 and 3)

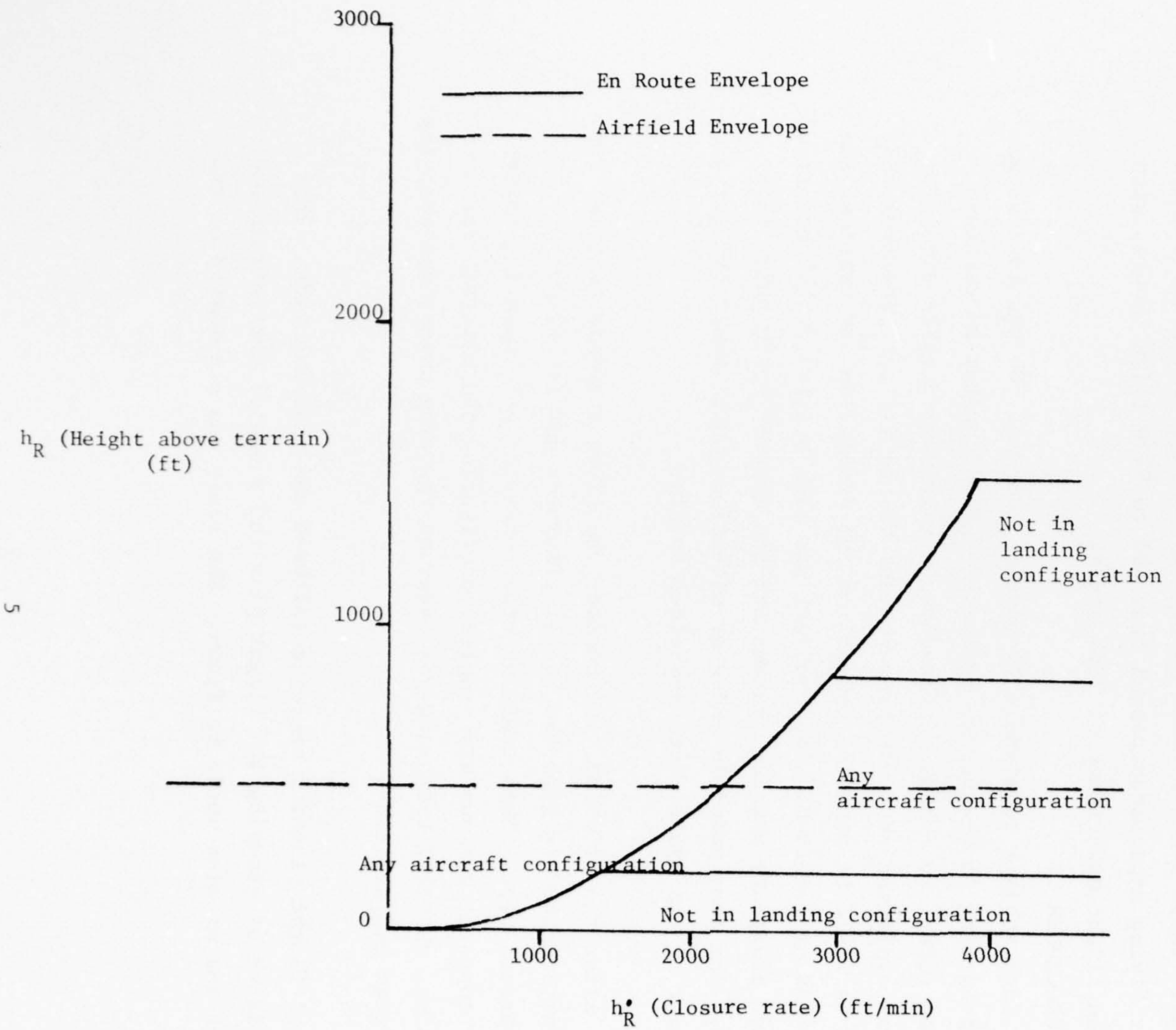


Figure 2 Proximity Warning Envelope (Closure Rate Modes 2 and 4)

SECTION III

STUDY PROCEDURE, PHASE I (VFR)

The first phase of the study was carried out under simulated Visual Flight Rules (VFR) conditions.

1. SUBJECTS

Twelve subjects took part in the first phase of the study; eight were rated USAF line pilots and four were Air National Guard pilots. Table 1 shows their qualifications and flying experience. Their flying experience ranged from 500 to 5400 flight hours, with a mean flight experience of 2880 hours.

2. PROCEDURE

Each subject received a 15 minute prebrief. He was told he was participating in a study to evaluate a ground proximity warning system (GPWS) in a high-performance, highly maneuverable aircraft. It was explained that his primary task was to fly the simulator, but that he would be asked to comment on the simulation and critique the warnings he received. Each subject was also briefed on the nature of ground proximity warning systems and the type of logic built into them. The four possible modes or situations which would trigger a warning by the system were explained to him.

After the briefing, the subject was given a 30-minute trial run to familiarize him with the FB-111 simulator and its flight characteristics. This training ride consisted of completing several 360° turns at various bank angles, configuring the aircraft for landing, shooting touch-and-gos, varying the wing sweep, and changing airspeed and altitude.

A flight planning exercise followed the training ride. This consisted of studying the flight plan and a map of the terrain over which the mission would be flown. The route was pre-marked on the map.

TABLE 1

PHASE I SUBJECT EXPERIENCE

Subject	Qualification	Type Duty	Flying Time (hrs)
1	Pilot	ANG*	900
2	Senior Pilot	Instructor Pilot	4000
3	Pilot	Test Pilot	500
4	Command Pilot	Aircraft Commander	4600
5	Senior Pilot	ANG	3100
6	Senior Pilot	Fighter Pilot	2800
7	Senior Pilot	Fighter Pilot	2100
8	Senior Pilot	Fighter Pilot	2300
9	Senior Pilot	Non-Flying Status	5400
10	Senior Pilot	ANG	3450
11	Pilot	ANG	1000
12	Senior Pilot	Fighter Pilot	4400

Average flying experience = 2879.12 hours.

*ANG - Air National Guard Fighter Pilot

Any questions the subject had regarding the mission, or what he was expected to do, were answered at this time.

3. MISSION

The VFR mission flight plan is described in Appendix A. There were four locations along the route where the pilot was scheduled to encounter situations which would cause him to receive one of the four modes of warning. These locations, however, were not marked on the subject's copy of the map. The four situations were:

a. An airpocket after a takeoff

b. Closure into "mountainous" terrain

c. Descent over a flat desert

d. Excessive descent rate

Ideally, these four situations in the mission placed the pilot in simulated conditions where he received each of the four modes of the GPWS:

a. Mode 3 - Altitude loss after climbout (negative climb rate)

b. Mode 2 - Excessive closure rate

c. Mode 4 - Unsafe terrain clearance based on airplane configuration

d. Mode 1 - Excessive descent rate (sink rate) with respect to the terrain.

4. EXPERIMENTAL DESIGN

Each subject was given two of the three methods of warning. He would sometimes receive them singly and sometimes simultaneously; e.g., during different parts of one mission, the pilot might receive a tone warning alone, a voice warning alone, or a voice and tone warning together (Whoop-whoop! Pull Up! Whoop-whoop! Pull Up!).

Table 2 shows the order in which the types of warning were presented to subjects.

5. DATA COLLECTION

An 8-channel Brush recorder was used to collect four aircraft parameters:

1) Delta stick (degrees)
2) Delta pitch (degrees)
3) Delta flight path vector (degrees)
4) Delta barometric height (feet)

and four pilot response parameters:

5) Plus and minus vertical velocity (feet per minute)
6) Radar altitude (feet)
7) Indicated airspeed (knots)
8) Percent throttle

The first parameters were recorded when the pilot entered a warning situation. The recording equipment took the instantaneous value of the four aircraft parameters at the time when the warning was triggered and recorded changes in stick movement, pitch, flight path vector, and barometric height throughout the duration of the warning. These four channels registered "0" as long as the pilot received no warnings, and ten seconds after the termination of a warning they reset to "0" again. The last four channels were plotted continuously during the entire mission.

TABLE 2

SCHEDULE OF WARNING SIGNALS

Subject	Mode 3	Mode 2	Mode 4	Mode 1
1	tone	voice/tone	voice/tone	tone
2	tone	tone	voice	voice
3	light	voice	voice/light	light
4	tone	light	light/tone	tone
5	voice	voice/light	light	voice
6	light	light/tone	tone	light
7	voice	voice/tone	tone	voice
8	voice/light	light	voice	voice/light
9	light/tone	tone	light	light/tone
10	voice	voice/tone	voice/tone	tone
11	voice	voice/light	voice/light	light
12	light	light/tone	light/tone	tone

In addition to the eight analog channels, the Brush recorder had two digital channels. One was used to record elapsed mission time and the other to indicate a warning condition. Thus it was simple to determine the point in time when the warning started and for how long it was activated.

A magnetic tape was also used to collect data, on the above parameters and a number of others, at a rate of 10 iterations per second. The tape data was collected as a backup to the Brush recordings.

6. QUESTIONNAIRE

In order to obtain pilot reactions to the quality and validity of the different warnings received, a questionnaire was developed (Figures 3 and 4). This questionnaire was aimed at gaining information about pilots' acceptance of the GPWS, their reactions to the different methods of presenting warning information, and the usefulness of such a system in the F-111 or in similar aircraft. The first part of the questionnaire was deliberately unstructured in the hope of attracting any original ideas the subjects might have concerning GPWS. The second part was structured to ensure that certain basic information was obtained.

GROUND PROXIMITY WARNING SYSTEM STUDY

TEST PROFILE

CRITIQUE-PART 1

NAME:

COMMENTS ON SIMULATION:

VISUAL:

MOTION:

SYSTEM RESPONSE/CONTROLS

COMMENTS ON WARNING SYSTEM:

TYPE OF SITUATION IN WHICH WARNING OCCURRED:

MERITS OF DIFFERENT METHODS OF PRESENTING WARNING INFORMATION:

Figure 3. Test Profile Critique-Part 1

GROUND PROXIMITY WARNING STUDY

TEST PROFILE CRITIQUE PART 2

1. Did you get any warnings that were
   a. Unnecessary?
   b. Too early?
   c. Too late?

2. Did you meet situations where you felt you should have been warned but were not?

3. During the course of the mission you received various types of warnings and combination of warnings. For each warning and combination of warnings, describe what you liked or did not like and for what reasons. Which warning did you feel was most effective?

4. Did you feel the system was useful or could be made useful.

   a. For general flight in F-111 or similar aircraft.
   b. For transit/ferry flight in F-111 or similar aircraft.

Figure 4. Test Profile Critique-Part 2

SECTION IV
STUDY PROCEDURE, PHASE II (IFR)

During Phase I of the study it was found that the visual cues a pilot receives, particularly if he has no lateral vision, may appear to him to conflict with the GPWS warnings. This problem is inherent in the GPWS, since the radar altitude data is always historical with respect to the pilot's forward field of view. Thus, an obstacle which has passed safely below the pilot's line of sight may still cause a momentary warning signal as the radar altimeter senses it. It was therefore decided to run a phase without this visual conflict, by using an IFR mission. This is in line with the expected use of the GPWS. To give the subjects some form of reference, the TF capability of the simulator was used, with the pilot in the control loop, i.e., the mission was flown manually using the ADI display.

1. SUBJECTS

In view of the high skill level required to fly the FB-111 on manual TF, and the need for familiarity with the TF to permit assessment of the GPWS against it, three experienced F-111 pilots were used as subjects for this phase.

2. PROCEDURE

Each subject was given the same prebrief as described in Phase I. He was then briefed on the requirement for manual TF flying and the type of terrain he would be flying over. He was given a map marked with the test route. The coordinates of the route were preset into the automatic inertial navigation system, with system output fed to the vertical bar of the ADI.

TF data was fed to the horizontal bar of the ADI. Thus, by manually flying the aircraft in response to the ADI command signals, the correct route was flown at the selected TF height. This was fully explained to each subject, and he was advised of the TF height selection and ride setting (either hard or soft) he would be using.

3. MISSION

The IFR mission flight plan is described in Appendix B. The mission was over terrain varying from 1000 feet to 6000 feet MSL with peaks to 9000 feet. The route was essentially along valleys, but in view of the speed (475 knt) the contours were not followed precisely, so there were considerable fluctuations in ground height along track.

4. EXPERIMENTAL DESIGN

Because of limitations on time and availability of subjects for Phase II, the experimental concept used was to progressively push the man in the loop towards the limit of the manual TF capability. The missions flown by each subject are detailed in Table 3.

5. DATA COLLECTION

The same data collection program as in Phase I was used, including Brush recorder, magnetic tape, and questionnaires. In addition to the above data, an experimenter recorded the time of warning, mode of warning, and any comments the subject made about the warning. The comments the subjects made as they received each warning during the IFR phase are given in Appendix B.

TABLE 3

TERRAIN FOLLOWING (TF) MISSION DATA

MISSION NUMBER	SUBJECT	HEIGHT (FT)	RIDE
1	1	1000	Hard
2		1000	Soft
3		750	Soft
4	2	750	Hard
5		750	Soft
6	3	750	Hard
7		400	Soft

NOTES:

1. Pitch was manually controlled throughout.
2. Indicated Airspeed was 475 knt throughout.
3. Mission one was flown with automatic roll control.
4. Mission three and all subsequent missions were flown with mode 1 (excessive sink rate) disabled.

SECTION V
RESULTS

The VFR and IFR phases of the experiment are independent and can be considered separately. A considerable amount of hard data was acquired for the VFR phase, whereas the IFR phase data was mainly a series of subjective assessments by the subject pilots.

1. PHASE I REACTION DATA

Although much hard data was recorded, it was not susceptible to precise or significant statistical analysis; although the study was initially designed with adequate data points and a measure of counter-balancing, various practical problems during the data collection weakened the design. An analysis of these problems is presented in Appendix C.

A wide range of parameters was recorded to ensure that an appropriate measure could be found. The data on the Brush recorder was found to be sufficiently comprehensive, and the back up data on tape was therefore erased to permit reuse of the tape and to save storage space.

As a result of inaccurate route flying, not only were some data points lost, but many warnings were received at points where none was intended, and these were not received consistently by all subjects. It was therefore considered inadvisable to use them for comparative purposes, but the data has been retained in case a more extensive analysis seems desirable at a later date.

Inspection of the various parameters showed them to be generally consistent but some were affected by factors outside the scope of this study; any data recorded more than 4 or 5 seconds after warning were affected by changes in ground height at or after

the time of warning. It appeared that a good measure of response to the warnings was given by the time to achieve certain criteria. For Modes 1 and 3, which are triggered by negative barometric rate, return to 0 barometric rate appeared to be a good criterion; whereas for Mode 2, which is triggered by radar rate, a gain in barometric height of 150 feet was used. Mode 4 was not considered, due to insufficient data (one data point). The times taken to achieve criterion values are shown in Table 4 together with the reciprocal times which represent rates of response. Since Mode 3 was the only mode for which data was obtained from every subject, the subjects have been arranged ordinally with respect to Mode 3 response time. No order is apparent in the related Mode 1 and 2 responses, which indicates that there are no consistent between-subject differences. The mean response rate for each warning mode is also shown in Table 4. To provide some degree of comparability between modes (since the modes have arbitrary and different criteria for measurement of response time), response rates within modes have been expressed as deviations from the mean response rate for that mode.

These deviations are grouped in Table 5 by nature of warning signal. Two general trends are apparent here:

a. Single warnings led to responses which, on balance, were better than the average response. Combined warnings, e.g., voice and light together, led to worse than average responses.

b. Within the single warnings, the response to voice was much faster than the response to tone or light.

It would be wrong to draw firm conclusions from this, since the data are not statistically significant, but there is enough evidence to suggest that further experiments specifically designed

TABLE 4

RESPONSE TIMES BY SUBJECTS AND MODES

W=Warning Signal   TTC=Time to Criterion   R=1/TTC $\bar{R}$=mean R   D=R-$\bar{R}$

	MODE 3				MODE 2				MODE 1			
Subject	W	TTC	R	D	W	TTC	R	D	W	TTC	R	D
10	V	4.0	0.250	0.097	TV	4.0	0.250	-0.043	T	4.0	0.250	-0.034
2	T	4.5	0.222	0.069	T	2.0	0.500	0.207	V	8.0	0.125	-0.159
7	V	4.5	0.222	0.069	TV	6.5	0.154	-0.139	V	2.5	0.400	0.116
12	L	5.5	0.182	0.029	LT	2.0	0.500	0.207	T	22.0	0.045	-0.239
3	L	6.0	0.167	0.013	V	4.0	0.250	-0.043	-	-		
11	V	6.0	0.167	0.013	VL	4.0	0.250	-0.043	-	-		
6	L	6.5	0.154	0.001	LT	4.0	0.250	-0.043	L	4-5	0.222	-0.062
8	VL	7.0	0.143	-0.010	L	5.5	0.182	-0.111	-	-		
4	T	9.0	0.111	-0.042	L	2.5	0.400	0.107	-	-		
1	T	10.5	0.095	-0.058	TV	3.5	0.286	0.007	T	2.25	0.444	0.160
5	V	11.5	0.087	-0.066	VL	5.0	0.200	-0.093	V	2.0	0.5	0.216
9	LT	25.0*	0.040	-0.113	-	-	-	-	-	-		
			$\bar{R}$=0.15330				$\bar{R}$=0.293				$\bar{R}$=0.284	

*=Nominal Value: Simulator Crashed

Warning Signal Codes: V=Voice T=Tone L=Light

TTC Criteria Values: Mode 3 $\dot{h}_{BARO} = 0$

Mode 2 $h_{BARO} = +150$ ft

Mode 1 $\dot{h}_{BARO} = 0$

TABLE 5

RESPONSE RATE DEVIATIONS BY WARNING SIGNAL

Warning Signal	T	V	L	TV	VL	LT
D	0.069	0.097	0.029	0.007	-0.010	0.207
	0.207	0.069	0.013	-0.043	-0.043	-0.113
	0.160	0.013	0.001	-0.139	-0.093	-0.043
	-0.042	0.116	0.107			
	-0.058	0.216	-0.111			
	-0.034	-0.066	-0.062			
	-0.239	-0.043				
		-0.159				
D_{TOT}	0.063	0.243	-0.023	-0.175	-0.146	0.051
n	7.0	8.0	6.0	3.0	3.0	3.0
$\bar{D}$	0.009	0.030	-0.004	-0.058	-0.049	0.017

n=Total number of warnings of type

$\bar{D}$= Mean D

to establish the relationship between type of warning and speed of response would be worth-while. There is also the suggestion that presenting two warnings simultaneously may have an adverse effect, whether due to some form of mental conflict over interpretation, or perhaps some anxiety associated with the intensifying effect of the double warning.

2. PHASE I QUESTIONNAIRE

Some comments from the questionnaire are given at Appendix D. Some general conclusions from these questionnaires are that:

a. Only one subject felt that the system failed to warn him of a dangerous situation.

b. Only two subjects felt that some of the warnings were too late.

c. Most subjects felt that some of the warnings were given too early, or were even, in some cases, unnecessary.

d. Only one subject felt that the system could <u>not</u> usefully be applied to high performance aircraft.

e. The subject's ratings of the various types of warning were imprecise verbal descriptions. On two separate occasions the experimenters independently transcribed these ratings onto a 1-5 scale (5=most favorable). These four transcriptions proved to be highly consistent both between experimenters and over a period of time. Average values are shown in Table 6, together with overall averages by warning signal. The subject's assessments are slightly in conflict with the reaction times in Table 4 and 5.

3. PHASE II REACTION DATA

It was quickly discovered in the first two tests flown under IFR conditions that the Mode 1 (rate of descent) warning, as currently configured, was useless for a terrain-following flight

TABLE 6

SUBJECT ASSESSMENT OF WARNING SIGNALS

SUBJECT NUMBER	VOICE	TONE	LIGHT	COMBINATION
1			4.50	
2	3.75	4.25		
3	4.00		4.00	5.00
4	4.00	1.75	3.50	
5	4.50		2.25	
6		3.25	4.25	4.50
7	5.00	4.00		
8	4.00		5.00	4.75
9		4.50	2.75	4.50
10	2.00	2.75	4.00	
11	4.75		3.00	4.75
12		4.00	1.00	4.25
AVERAGE	4.00	3.50	3.43	4.63

(Numerical values assigned by experimenters on the basis of subjects' verbal ratings. Scale 1-5, 5 most favorable.)

path. Given a good terrain following signal, it is quite safe to climb and descend at rates well into the GPWS Mode 1 envelope. On the other hand, because of the tendency to maintain constant terrain clearance, the Mode 2 envelope remained relatively usable at much lower altitudes than might have been expected. Once the Mode 1 had been disabled, the Mode 2 warnings were found to be mostly appropriate. However, the subjects felt that, assessed against the available TF cues, the GPWS warnings were slightly later than they would have liked.

These results are not an indictment of the GPWS; they simply indicate that it is not as flexible, precise, or responsive as a higher grade system. On the other hand neither is it so heavy or so costly, and it was never intended to cope with the type of environment used in this study. Unfortunately, this adverse comparison with the TF system (which, being fitted to all F-111s, provided an easy base reference) led all the experienced F-111 pilots to deprecate the GPWS because it would not result in any improvement to the F-111 as they knew it.

4. PHASE II QUESTIONNAIRE

Some comments from the questionnaires are given in Appendix E. An examination of the subjective comments given by the subjects at the time of each warning shows that the terrain following radar (TFR) system is felt to be superior to the ground proximity warning system. Many comments pointed out that the ground proximity system could only look at the terrain directly beneath the aircraft while the TFR could look forward at upcoming terrain. In the majority of the cases the two systems working together led to confusion for the pilots. The TFR pitch command sometimes gave the pilot a pitch down command at the same time as the ground proximity system was telling the pilot to "PULL UP!".

SECTION VI

CONCLUSIONS

Although in many ways the study appears to have been inconclusive, in terms of hard data and significant results, in fact it has led to a considerably better understanding of the implications of the GPWS.

It is clear that, with the exception of the negative response exhibited by TF experienced pilots, there was a high degree of pilot acceptance. This would presumably be reinforced by a suitably developed GPWS which produced more consistently acceptable warnings.

Some preconceived ideas were upset regarding the relative suitability of GPWS for different types of aircraft and mission. There appears to be some degree of trade-off between the ease with which a high performance aircraft can get into trouble and its ability to get out. With the exception of the terrain following situation it appeared likely that a workable series of envelopes could be developed for combat aircraft. Further studies, preferably in flight, should be made. On the other hand, parallel studies with the GPWS in-flight on a KC-135 suggest there could be a greater problem with transport aircraft than was expected because of higher load factors on military aircraft and the need for tactical flight profiles. The inability of the system to cope with terrain following is not a serious shortcoming since the whole concept of Ground Proximity Warning is predicated on "inadvertent flight into terrain" which is, by implication, from a nominally safe height.

There appears to be some evidence that the voice warning has benefits despite the fact that it was not particularly favored by

the subjects. This is certainly worth pursuing in a dedicated study. CSDF initially had some reservations about the use of the warning "Pull Up", but after some analysis it was retained for the study and is currently favored by CSDF. The rationale for this, briefly, is that:

a. The system can only work if nuisance warnings are avoided.

b. This can only be achieved by keeping the envelopes small.

c. GPWS is not a routine flight aid, but an emergency warning for an aircraft which has inadvertently entered a dangerous flight condition.

d. Warning will always be at the last minute.

e. Instant response, without the delay which would be caused by assessing possible failures, is needed.

f. The warning "Pull Up", while not universally appropriate, offers the chance of saving more aircraft than a more complex or more abstract warning.

As stated above, however, this is an analytical judgement and we know of no data on alternative voice messages for GPWS. Work in this field is currently being undertaken at NASA, Ames Research Center, and close cooperation for the future is strongly recommended.

APPENDIX A
VFR MISSION PROFILE

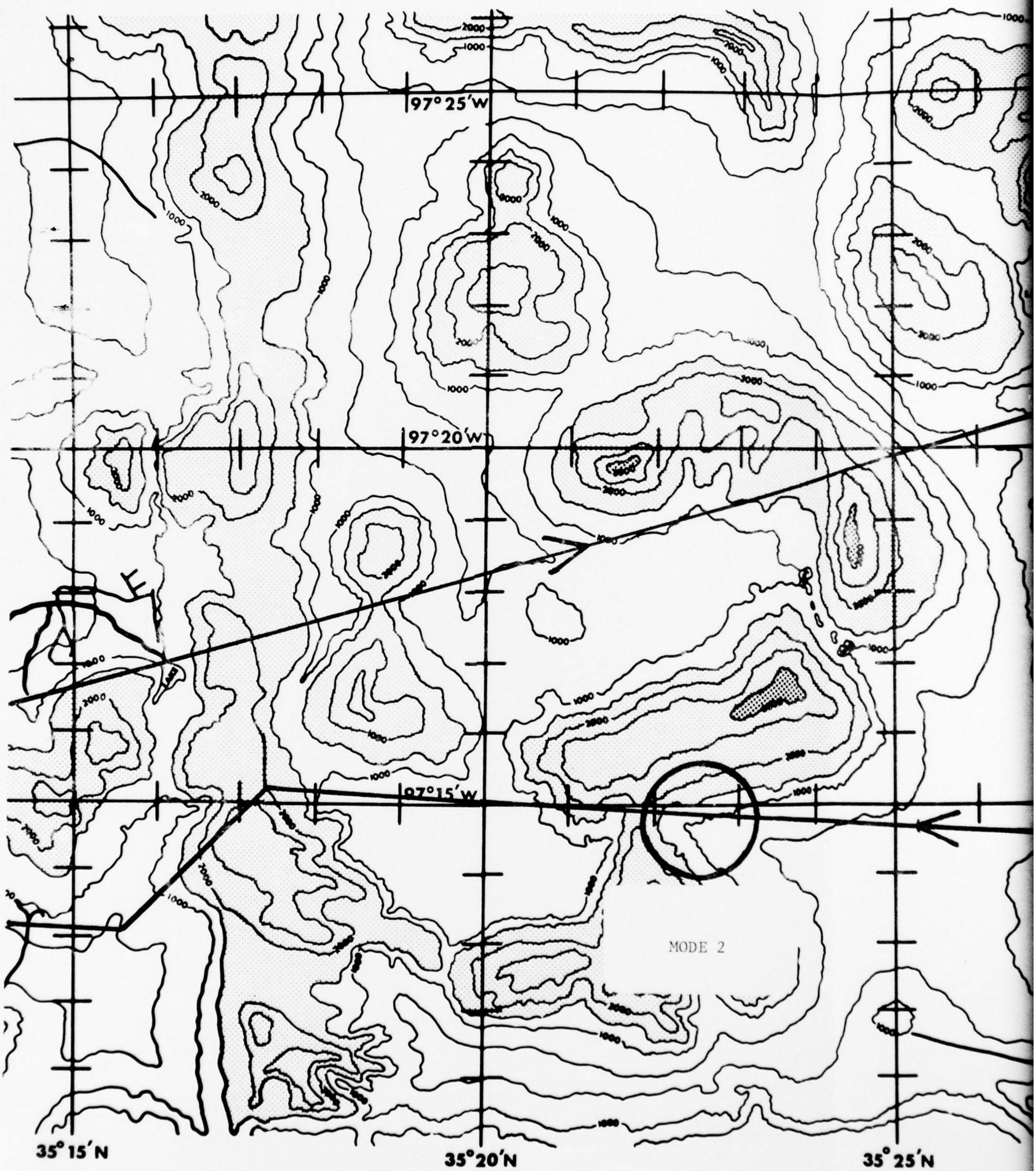
The VFR mission was flown over the visual terrain model of the F-111 simulator. This is a SMK 23 model which was extensively remodeled for this study. Figure A-1 is a map of the model, showing part of the mission route. Table A-1 shows the flight plan which was given to the subjects.

TABLE A-1

FLIGHT PLAN FOR PHASE I MISSION

Leg	Description	Heading (Degrees)	Leg Dist (NM)	Indicated Airspeed (Kts)	Leg Time (Min/Sec)	Cum Time (Min/Sec)	Altitude (MSL) (Ft)
1	Take off and climb to 4000 ft.	028	17	450	2:31	2:31	4000
2	turn left onto 003	003	15	450	2:00	4:31	4000
3	turn onto a heading of 346	346	18	450	2:24	6:55	4000
4	slow up and configure for landing; descend to 1400 ft.	346	12	160	4:30	11:25	1400
5	touch and go landing; then climb to 3000 ft. on runway heading and turn right onto 150	150	6	450	:50	12:15	3000
6	descend to 2500 ft. and turn onto 183	150	10	450	1:20	13:35	2500
7	start climb back up to 3000 ft.	183	13	450	1:44	15:19	2500
8	negotiate an S-turn, first onto 135 then to 182 heading	135 182		450	:16	15:35	3000
9	descend at a rate of 500 ft/minute to 1800 ft.	182	23	450	3:04	18:39	1800

10	climb out to 5000 ft. and make a heading change onto 201	201	13	450	1:44	20:23	5000
11	turn to heading of 185	185	16	450	2:08	22:31	5000
12	make a left turn onto 338	338	7	450	1:25	23:56	5000
13	start a descent of 2000 ft/minute down to 3500 ft.	338	24	450	3:12	27:08	3500
14	make a heading change onto 006 and descend to 3000 ft.	006	5	450	:40	27:48	3000
15	turn right onto 042	042	3	450	:24	28:12	3000
16	turn left onto 338, begin descending at 2000 ft/min. and configure the aircraft for landing	338	8	160	3:00	31:12	2000


97° 25' W
97° 20' W
97° 15' W
35° 15' N
35° 20' N
35° 25' N
MODE 2

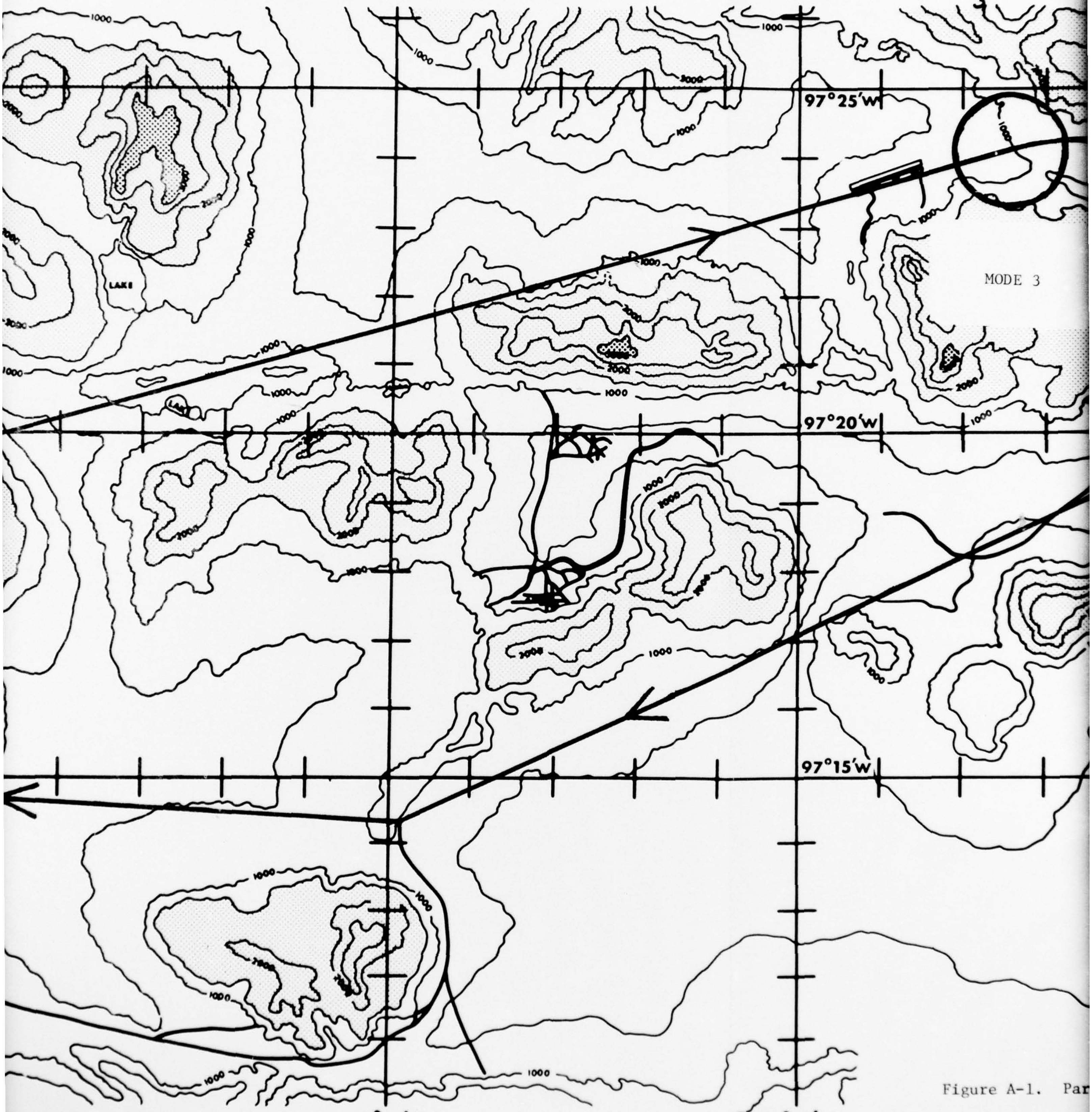


Figure A-1. Par

2

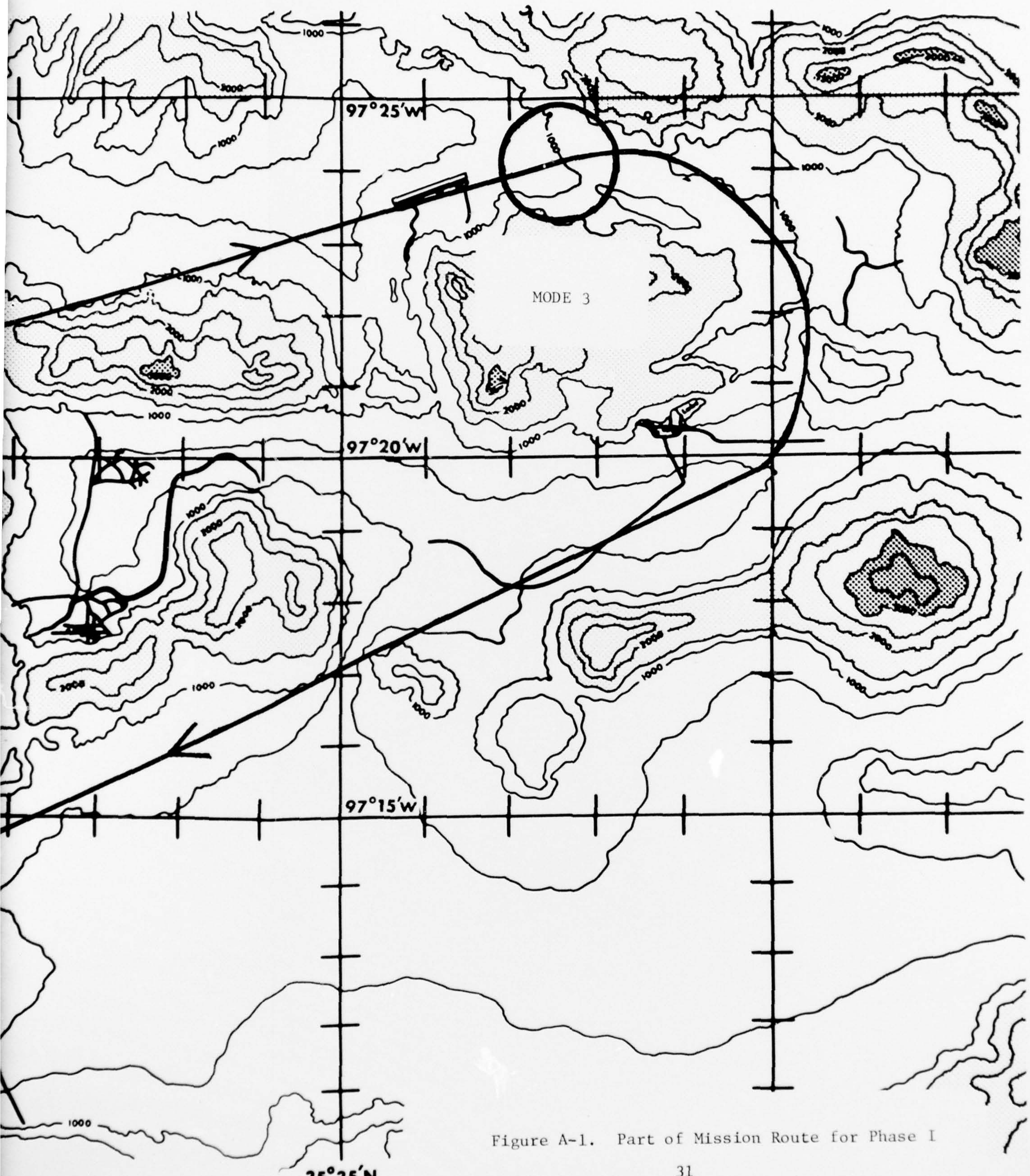
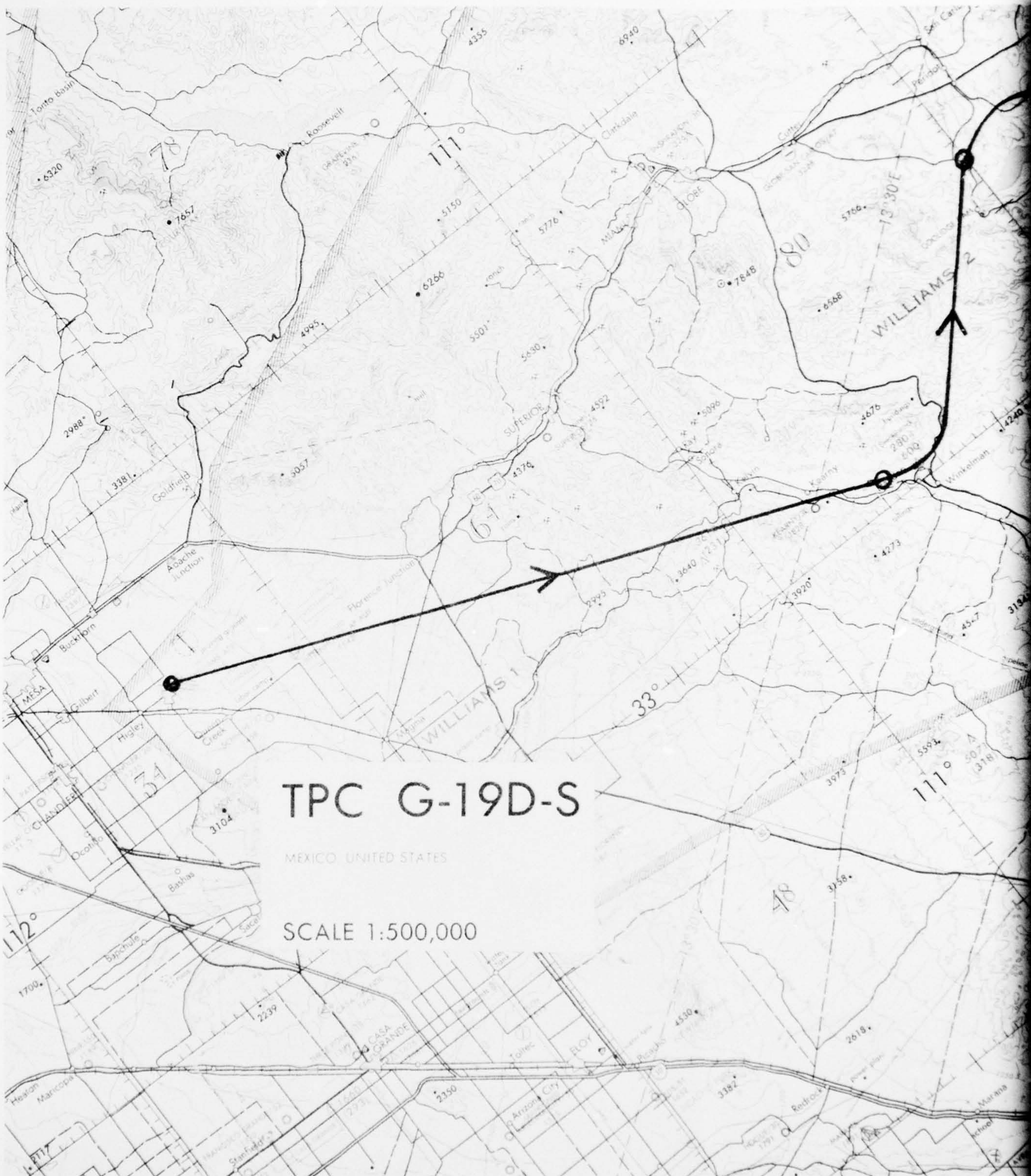


Figure A-1. Part of Mission Route for Phase I

3

APPENDIX B
IFR MISSION PROFILE

The IFR mission was flown over a radar simulation of southeastern Arizona, using a radar landmass plate. The route followed is shown on the map in Figure B-1. The route plan was programmed into the automatic navigation system so there was no need to give the subjects a flight plan.



TPC G-19D-S
MEXICO UNITED STATES
SCALE 1:500,000
Tonto Basin
Roosevelt
Globe
Miami
Cutter
Superior
Goldfield
Apache Junction
Florence Junction
Mesa
Gilbert
Higley
Chandler
Williams 1
Williams 2
Kearny
Winkelman
Casa Grande
Toltec
Eloy
Picacho
Redrock
Marana
Maricopa
Arizona City
Stanfield
111°
112°
33°

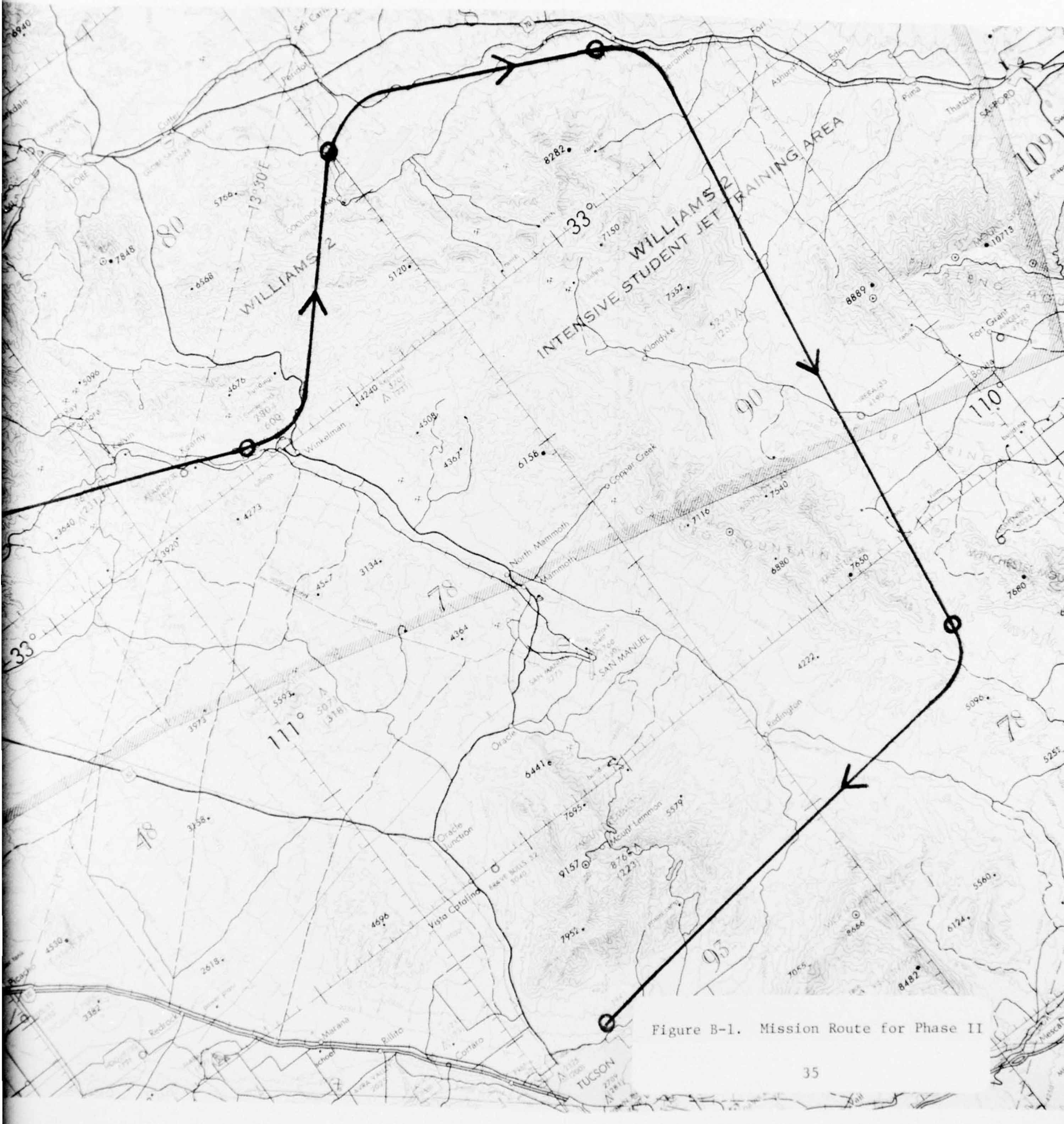


Figure B-1. Mission Route for Phase II

2

APPENDIX C

PROBLEMS AFFECTING EXPERIMENTAL DESIGN

There were three basic problems which interfered with the experimental design, and made it impossible to apply any rigorous statistical analysis to the data. One was the difficulty in obtaining suitable subjects. More important was the problem of achieving consistency in navigation. Finally, there were some short-comings in simulation fidelity.

AVAILABILITY OF SUBJECTS

The experiment was essentially a low budget project with all available funds being applied to the development of the necessary hardware for radar altimeter simulation. It was also an internal ASD project so that there was no user command sponsorship. As a result, all the subjects were on-base volunteers from Wright-Patterson AFB, who had to be scheduled at times convenient to them and to their commanders. Their schedules also had to be closely coordinated with the schedule for the FB-111 simulator, which shares its computer with other simulator facilities. Specific effects of these factors were:

a. There was no spare pool of subjects to permit subject selection or flexible scheduling.

b. Most subjects were not familar with the F-111, and those who were familiar were not current.

c. Time was not available for extra training or for reruns.

The net result of these problems was that the skill levels of the subjects differed widely, and the average level was lower than could have been wished for. Any problems in administering or recording the test runs had to be accepted since there was no time available for reruns.

NAVIGATION PROBLEMS

The available terrain model for flying the tests represents very rugged country. Although this was good in the way it simulated a high risk area where GPWS might be important, it had the major drawback that very small changes in height, position, or heading generated major changes in the aspect of the terrain presented to the system and the pilot. When this is considered in conjunction with the low skill level mentioned in the previous paragraph, it will be seen that there was little chance of presenting consistent situations to the subjects. The test routes were chosen to produce four specific warnings. In practice the four warnings were generated under widely differing situations from test to test, or in some cases the system did not trigger a warning at all. In particular, Mode 3 was generally swamped by Mode 1 signals, and Mode 4 was only achieved by one subject. On the other hand, many warnings were generated at points where none were intended; the pilot was therefore specifically instructed, as he approached some of these situations, to ignore the inadvertent warning. Although this procedure was undesirable, since it probably had some interaction with his reaction to other warnings, it appeared to be the most workable and expedient solution to the problem.

These inconsistencies in the conditions under which the four planned warnings were generated had the following effects:

a. The visual cues, and the timing of the warning relative to these cues, were not constant.

b. The aircraft flight vector and position were not constant.

c. The impending crisis to be recovered from was not constant.

Any attempt at precise comparisons would therefore be suspect.

SIMULATION FIDELITY

Two areas of simulation had insufficient fidelity to guarantee meaningful results. The radar altimeter simulation, which was a state-of-the-art facility specifically produced for this study, was still liable to produce occasional erratic outputs as a result of its sensitive nature and the heavy filtering used to compensate for this. Thus, it is possible that not all warnings were generated at precisely the correct time to simulate a real GPWS. No quantitative assessment of this problem was attempted.

The second problem was in the visual cues available to the pilot, which were restricted by the 45° (diagonal) field of view of the simulator. Mountain peaks were perceived by the subjects to disappear below the field of view, and mentally dismissed as already passed. From the aircraft safety point of view this dismissal is correct as the pilot can correctly assess he will not hit the peak. However, the GPWS, with no forward looking facility, will subsequently "see" the peak below, and give warning. If the peak is 500 feet below, and the ground speed is 400 knt the warning may occur up to 3 seconds after the peak disappears; at lower speeds the time will be commensurately longer. To the pilot, who has now ceased to consider the peak as a threat, this rates as a "nuisance" warning. The 15° downward field of view is realistic, but more visual cues out to the side would help him to assess the time of passing over an object.

CONCLUSION

The combined effect of these various problems caused the loss of some data points and made others suspect in varying degrees. It was therefore not considered legitimate to carry out a formal statistical analysis, but a general trend assessment was made.

APPENDIX D

PILOTS COMMENTS ON VFR MISSION

I. COMMENTS ON AND SUGGESTIONS FOR WARNING SYSTEM:

A. PRO

"Warning system was O.K. but it would be helpful to know what approximate limits are required to set it off and safely 'escape'."

"... Would like an indication of the type of warning indicated, i.e. too low, sink rate, etc."

"... Would possibly like to see three separate forms of warning, e.g., voice: PULL UP/LEVEL OFF/GO ROUND."

"... The too rapid descent signal should be differentiated from the too low signal."

"The system could be made useful particularly in weather or instrument approaches to strange fields."

"System could be useful as a warning system in the F-111 or similar aircraft, but not as means of conducting low-level terrain avoidance flight."

"The most useful time for the warnings seems to be during take-off and landing, but during high-speed phases I have doubts about its usefulness because it does not look ahead of the aircraft."

B. CON

"There were several warnings that occurred when I felt the aircraft was well within the envelope of safe clearance considering the maneuverability of that type of aircraft."

"A system that cries 'wolf' too often will be ignored; and the system seemed to give warnings too often, especially during landing approaches as compared with visual information."

"... maybe a longer time delay between an out-of-envelope condition and a warning signal would reduce the warnings caused by momentary pitch inputs."

"... landing warnings in VMC are not necessary-could distract during visual approaches or during VMC flight."

"This system is a duplication of the TFR and can't be used for TFR flight missions."

"It could be of some use; however, existing warning systems tend to make the addition of this cost-prohibitive."

II. SUMMARY OF SUBJECTS WHO FELT THEY RECEIVED WARNINGS THAT WERE:

unnecessary-11 out of 12 subjects, in situations such as low altitude approach, slow descent over the desert and clearing some terrain.

too early- 6 out of 12 pilots said "yes" for reasons such as during rapid rates of descent and flying over some terrain.

too late- only one subject thought a warning was too late ".... I believe it was when we approached a mountain top and an excessive rate of pitch up was required to stop the (voice) warning."

III. COMMENTS RECEIVED ON THE THREE TYPES OF WARNING (LIGHT, TONE, VOICE) AND COMBINATION OF THE WARNINGS:

LIGHT

A. PRO

"Prefer the visual warning."

"I like light better than the tone, it was more effective."

"The light warning is in a good location."

"... light better cue than audio due to faster response especially during IMC to a visual cue. .... Light alone may be missed.

Light location good-in F-111 the location could be confused with TF fail light, but both require the same response. For a single warning I feel light is more effective due to my tendency to respond to visual cues more rapidly than audio (ones)."

"Did not encounter light, but feel it would be more distinctively identifiable than aural signals. ... visual signal such as in simulation is much preferred in my opinion because it is immediately identified as a terrain avoidance signal so pilot's response is probably much quicker."

B. CON

"I did not respond to the light at the time even though I consciously saw it."

"... red lights in cockpit scare fighter pilots. Blinking or steady red lights in cockpit cause distraction when attention should be outside the cockpit."

"Warning light not always noticed when it came on while flying visually."

TONE

A. PRO

"Liked this best, however type of tone should be changed. Sounds too much like an emergency beeper."

"I liked the tone ... should be loud enough to "wake you up."

"Tone warning seemed to get my attention quicker at first..."

B. CON

"I think the tone should be louder and used in conjunction with the light."

"Aural signals in general can easily be masked out by intercom, UHF communication, RHAWS warnings, gear warning, aircraft noise, etc. (Particularly in a combat environment.)

"... could be easily confused with the emergency beeper on personal locator beacon."

VOICE

A. PRO

"Voice is better than light expecially in landing phase."

"Liked this signal the best because it is enough different from all other aircraft warnings to get your attention quickly. Unecessary warnings could defeat this advantage though."

"... always noticed - good attention getter ... regardless of circumstances."

B. CON

"... change the voice that recorded it! It sounded too much like a robot and it got on my nerves."

"Voice not preferred due to large number of other UHF communications in a combat environment."

"... did not trigger a response at first because of similarity to radio/interphone transmissions. A female voice or a combination of tone/voice might have been better."

COMBINATIONS

"Both warnings (light and voice) together are effective."

"Tone and light good for last chance warning, i.e., tone only in caution area, then light also when terrain gets very close."

"The aural tone and light combination are good (built-in backup and calibration)."

"Ought to have both audio and visual "PULL UP" warning come on at the same time."

APPENDIX E

PILOTS COMMENTS ON IFR MISSION

The following are comments made by the pilots during the actual running of the IFR portion of the simulation. The subjects were instructed to comment on each warning as they received it, i.e., was it valid, a nuisance, inconsistent with the TFR pitch command.

"... That was very confusing, ground proximity is telling me to pull up and an opposing point of view from the TFR pitch command telling me to pitch down."

"Two conflicting points of view and a person will tend to ignore one or the other."

"... change parameters so a warning won't come on as often."

"TFR doesn't give you any warning because it looks ahead and knows the glitches in the radar altimeter are only temporary."

"No indication of radar altimeter dropping but we are getting warnings."

"Warning ground proximity is giving me information that TFR is not, but need training to see what the warning means."

"these (warnings) are all ridiculous since I'm getting the pitch down command on the TFR."

"I was in an 80° climb and I still got a warning."

"it (warning) turns on at 500 feet and TFR is set to fly at 400 feet."

"... ignore the system, the GPWS is annoying."

"Warnings are very distracting with TFR."

"Sink rate warning is coming on. TFR ignores sink rate directly. It is radar rate for TFR. False warnings should be eliminated with TFR set on soft ride."

"no good reason for that one."

"yes, we were closing then."

"going around corners seems to trigger a warning."

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